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# The Operation and Maintenance of Fluorescent Lamp Installations

By W. A. R. STOYLE, B.Sc., A.M.I.E.E. *(Fellow)*,
and G. D. JONES-THOMAS *(Member)*

**Summary**

Because of the many new ratings of lamps and new circuits, the operation and maintenance of fluorescent lamp installations has brought fresh responsibilities to the maintenance engineer. Effective maintenance requires fundamental knowledge of lamps and their associated circuits. This paper, therefore, deals with lamp and circuit characteristics from a practical point of view.

A detailed description of circuit components is also given, together with recommended testing methods and advice as to how troubles can be detected, identified and remedied.

**Contents**

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(2) RATINGS OF STANDARD FLUORESCENT LAMPS.
(3) CHARACTERISTICS OF THE FLUORESCENT LAMP.
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- (3.2) Life.
- (3.3) Electrical Characteristics.
- (3.4) Power Factor.
- (3.5) Effect of Mains Voltage Variation.
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- (9.4) Chokes and Capacitors.
- (9.5) Wiring Faults.
- (9.6) Premature Blackening.

(10) CONCLUSIONS.

## (1) Introduction

The rapidly expanding use of fluorescent lamps has created a need for a complete knowledge of their characteristics among those responsible for their operation, maintenance, and servicing. Most maintenance engineers are quite familiar with the servicing of tungsten filament and ordinary high-pressure mercury vapour lamp installations, but, as is only natural in this comparatively new field of the lighting art, few have much fundamental knowledge of the fluorescent lamp and its associated auxiliary equipment. Until recently the maintenance engineer had only to contend with two ratings of fluorescent lamps, the 5-ft. 80-watt and the 4-ft. 40-watt, but the range now covers lengths from 18 in. to 8 ft.; and wattages from 15 up to

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125. Whilst the new ratings have the same principle of operation, new circuits have been developed for them, and our basic knowledge of these lamps must, therefore, be widened.

The satisfactory performance of the fluorescent lamp depends not only on the use of correctly designed control equipment but on the air temperature and humidity, as well as the supply voltage, which has become increasingly variable during recent years. The effects produced by these varying external conditions can be very similar to those produced by defective or incorrect control gear, and this may lead to confusion. The maintenance engineer should therefore have adequate testing equipment, so that individual components as well as operating conditions may be tested.

## (2) Ratings of Standard Fluorescent Lamps

The complete range of standard fluorescent lamps is shown in Table 1. With the exception of the 18- and 24-in. lamps, all sizes require a mains voltage of 200/250. All 18- and 24-in. lamps may be operated singly on 100/130 volts or two in series on 200/250 volts. In addition, the 18-in. 15-watt and 24-in. 20-watt lamps may be operated singly on 200/250-volt supplies on suitable circuits.

Operation of the 24-in. 40-watt lamp singly on 200/250 volts is not recommended because of the large choke with would be necessary and its high wattage loss.

### Table 1.

**Range of Fluorescent Lamps—Ratings and Dimensions.**

| Lamp | 125/75 watts | 70/50 watts | 80* watts | 40 watts | 30 watts | 40 watts | 20 watts | 15 watts |
|---|---|---|---|---|---|---|---|---|
| Overall length ... (Nominal) | 96±0.25 in. | 93⅜± 0.25 in. | 60.1± 0.25 in. | 48 in. | 36 in. | 24 in. | 24 in. | 18 in. |
| Diameter ... ... | 38±1.5 mm. | 26±1 mm. | 38±1.5 mm. | 38±1.5 mm. | 26±1 mm. | 38±1.5 mm. | 38±1.5 mm. | 26±1 mm. |
| Cap ... ... ... | BC | Cylindrical centre contact | BC | Bi-pin | Bi-pin | Bi-pin | Bi-pin | Bi-pin |
| Length, including pins in both ends (max.) | — | — | — | 47 $\frac{25}{32}$ in. | 35 $\frac{25}{32}$ in. | 23 $\frac{25}{32}$ in. | 23 $\frac{25}{32}$ in. | 17 $\frac{25}{32}$ in. |
| Length, including pins in one end only ... | — | — | — | 47½+ 0-$\frac{5}{32}$ in. | 35½+ 0-$\frac{5}{32}$ in. | 23½+ 0-$\frac{5}{32}$ in. | 23½+ 0-$\frac{5}{32}$ in. | 17½+ 0-$\frac{5}{32}$ in. |
| Length, excluding pins (max.) | — | — | — | 47 $\frac{7}{32}$ in. | 35 $\frac{7}{32}$ in. | 23 $\frac{7}{32}$ in. | 23 $\frac{7}{32}$ in. | 17 $\frac{7}{32}$ in. |

* Also with starting strip for use with " instant start " circuits.

## (3) Characteristics of the Fluorescent Lamp

The factors with which the maintenance engineer is most concerned are life and light output and (since these depend on the lamp being operated at its correct wattage) its electrical characteristics. In the following section of this paper, however, some other subsidiary characteristics are included for the sake of completeness.

### (3.1) Light Output and Efficiency

The light output of the fluorescent lamp falls off somewhat during life, partly due to the deposition of a film of mercury on the fluorescent coating and partly because of actual chemical attack on the coating by the mercury vapour.

The light output falls off more rapidly during the first 100 hours or so, but after this initial drop the decline is extremely gradual, and even at the end of normal rated life the light output is some three times that of a filament lamp of equivalent wattage. The relation between efficiency and life for a typical 5-ft. 50-watt lamp is shown in Fig. 1. The fall in light output is not generally accompanied by any noticeable change in the colour of the light.

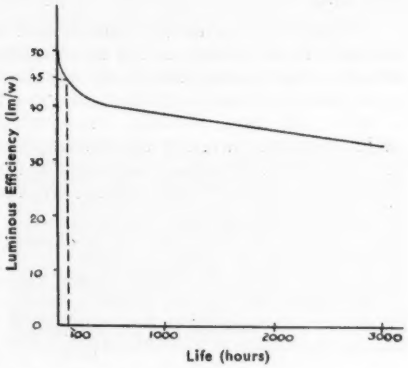



Fig. 1. Efficiency-Life relationship for a typical 5-ft. 80-watt fluorescent lamp.

"Initial" efficiencies are always quoted at 100 hours, but for service and design calculations the "average throughout life" figure is generally taken. Table 2 indicates the initial and average efficiency and lumen outputs for the complete range of fluorescent lamps.

## Table 2.

### Efficiency and Light Output.

| Lamp Rating | Colour | Efficiency in lm/w | | Light Output in Lumens | | Approx. Brightness in candles per sq. in. (100 hrs.) |
|---|---|---|---|---|---|---|
| | | Initial (100 hrs.) | Average throughout life | Initial (100 hrs.) | Average throughout life | |
| 8 ft. 125 watt | Natural | 46 | 39 | 5,750 | 4,875 | 4.5 |
| 8 ft. 70 w. | Natural | 51 | 42 | 3,570 | 2,940 | 4.2 |
| 5 ft. 80 w. | Daylight and Warm White | 45 | 38 | 3,600 | 3,040 | 4.5 |
| 5 ft. 80 w. | Natural | 41 | 34 | 3,280 | 2,720 | 4.1 |
| 5 ft. 80 w. | Colour matching | 36 | 30 | 2,880 | 2,400 | 3.9 |
| 4 ft. 40 w. | Daylight and Warm White | 50 | 43 | 2,000 | 1,720 | 3.2 |
| 4 ft. 40 w. | Natural | 45 | 38 | 1,800 | 1,520 | 2.9 |
| 3 ft. 30 w. | Warm White | 46 | 40 | 1,380 | 1,200 | 4.3 |
| 3 ft. 30 w. | Natural | 42 | 36 | 1,260 | 1,080 | 3.9 |
| 2 ft. 40 w. | Warm White | 33 | 29 | 1,320 | 1,160 | 4.5 |
| 2 ft. 40 w. | Natural | 30 | 26 | 1,200 | 1,040 | 4.1 |
| 2 ft. 20 w. | Warm White | 38 | 31 | 760 | 620 | 2.4 |
| 2 ft. 20 w. | Natural | 34 | 28 | 680 | 560 | 2.2 |
| 1½ ft. 15 w. | Warm White | 34 | 28 | 510 | 420 | 3.4 |
| 1½ ft. 15 w. | Natural | 31 | 25 | 465 | 375 | 3.1 |

**(3.2) Life**

Apart from accidental failures, such as glass cracks, etc., the failure of the lamp is caused by exhaustion of the electron emissive material on the filamentary electrodes, which is disintegrated slowly throughout life. A very slight momentary loss occurs each time the lamp is switched on; thus the number of switchings during the life of a lamp influences its life. However, the rated average life should easily be achieved with an average of three to four hours per switch, but if this number of switchings is very greatly exceeded a shorter life may result. The present rated average life of fluorescent lamps is given in Table 3 below.

**Table 3.**

**Fluorescent Lamp Life (Average)**

| Lamp Wattage | 125/75 | Life | 3,000 hours |
|---|---|---|---|
| ,, ,, | 70/50 | ,, | 2,500 ,, |
| ,, ,, | 80 | ,, | 3,000 ,, |
| ,, ,, | 40 (4 ft.) | ,, | 2,500 ,, |
| ,, ,, | 30 | ,, | 2,500 ,, |
| ,, ,, | 40 (2 ft.) | ,, | 2,500 ,, |
| ,, ,, | 20 | ,, | 2,500 ,, |
| ,, ,, | 15 | ,, | 2,500 ,, |

Throughout the life of a lamp. the gradual disintegration of the electrode coating generally causes slight blackening over one or two inches at the ends.

**(3.3) Electrical Characteristics**

Once the lamp has " struck " the voltage across, it will be about 50 per cent. of the total mains voltage. Details of starting and running currents and lamp voltages are given in Table 4 below.

**Table 4.**

**Electrical Characteristics of Fluorescent Lamps.**

| Lamp Watts | 125 | 75 | 70 | 50 | 80 | 40 | 30 | 40 (2 ft.) | 20 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|
| Approx. Lamp Starting Current (amps) | 1—1.6 | — | — | — | 1—1.6 | 0.5—0.75 | 0.4—0.65 | 1—1.6 | 0.4—0.7 | 0.35—0.7 |
| Approx. Lamp Running Current (amps) | *0.85 (I) 0.9 (C) | 0.4 | 0.5 | 0.2 | 0.85 | 0.41 | 0.34 | 0.85 | 0.35 | 0.5 |
| Approx. Lamp volts | 170±10 | 210±10 | 263 | 295 | 106.5±5 | 108±5 | 103±5 | 50±4 | 64±4 | 56±4 |
| Approx. Lamp Starting volts (8 ft. lamps) | 370 | 450 | 750 | 750 | — | — | — | — | — | — |

* I = Inductive. C = Capacitative.

In the capacitative branch of the "twin-lamp" circuit, described in a later section, the starting current is substantially the same as the normal running current.

The current through the lamp itself is sensibly in phase with the applied voltage, but because the voltage wave-form is distorted the power factor of the tube alone is only about 0.9. The wave-form is distorted because the discharge current during each half-cycle does not commence until the voltage has risen to a certain value (the striking voltage) and ceases to flow before the voltage falls to zero (the extinguishing voltage). An oscillogram of voltage and current is shown in Fig. 2.

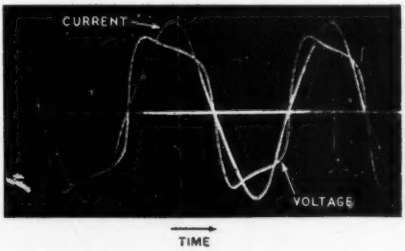



Fig. 2. Fluorescent lamp current and voltage waveforms (50 cycle supply).

Thus the calculation for an 80-watt lamp, taking the figures in Table 4, would be 105 x 0.85 x 0.9 = 80 watts, that is, the product of the lamp volts, lamp current, and lamp power factor.

For stable operation the mains voltage must be about twice the lamp voltage. Consideration of Table 4 above will show that for operation from 200/250-volt mains, lamps of 4 ft. and above can only be operated singly, but 18-in. and 24-in lamps may be operated in series.

### (3.4) Power Factor

The necessary use of an inductance (the choke) in series with the discharge introduces a lagging power factor into the circuit, the combined power factor of the lamp and choke being about 0.5. Using a suitable capacitor, the power factor of the circuit can be raised up 0.9, and by the use of the "twin-lamp" circuit practically unity power factor can be achieved. Values of capacitors for both parallel and series correction are discussed in section (5.2); Table 5 shows the approximate *mains* currents for various lamps and circuit arrangements.

## Table 5.

**Approximate mains current when power factor is corrected by means of the recommended capacitor.**

| Lamp | Circuit | Approximate current |
|---|---|---|
| 8 ft. 125 watt ... ... | Single lamp | 0.8 Amps. |
| 8 ft. 70 watt ... ... | ,, ,, | 0.46 ,, |
| 5 ft. 80 watt ... ... | ,, ,, | 0.5 ,, |
| | Twin lamp | 0.8 ,, |
| 4 ft. 40 watt ... ... | Single lamp. Inductive | 0.25 ,, |
| | Twin lamp | 0.4 ,, |
| 3 ft. 30 watt ... ... | Single lamp. Inductive | 0.18 ,, |
| | Twin lamp | 0.33 ,, |
| 2 ft. 40 watt ... ... | Two-in-Series | 0.5 ,, |
| 2 ft. 20 watt ... ... | Two-in-Series | 0.25 ,, |
| | Single | 0.15 ,, |
| 1½ ft. 15 watt ... ... | Two-in-Series | 0.18 ,, |
| | Single | 0.12 ,, |

### (3.5) The Effect of Mains Voltage Variation

When a metal filament lamp is operated at more than the designed voltage both the total light emitted and the wattage consumed increase (at, of course, the expense of life). As the light emitted by the lamp increases at a greater rate than the wattage, the efficiency in lumens per watt also increases. With the fluorescent lamp, however, an increase in mains voltage results in an increase in total light and in wattage consumed; but as the wattage increases at a greater rate than the light output, the efficiency in lumens per watt actually decreases because at the higher current density the short ultra-violet radiation (2,537 A deg.) is produced less efficiently.

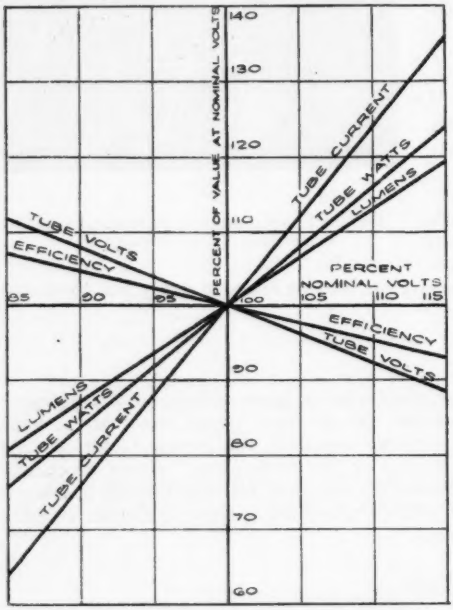



Fig. 3. Effect of mains voltage variation on the characteristics of a typical 80-watt fluorescent lamp.

The light "regulation" of the fluorescent tube with varying mains voltage, is considerably better than that of the metal filament lamp. With a metal filament lamp a 1 per cent. increase or decrease in the mains voltage results in about a 3½ per cent. increase or decrease in the light output. In the fluorescent tube, however, a 1 per cent. increase or decrease in the mains voltage only results in approximately a 1 per cent. increase or decrease in light output. (Fig. 3.)

The general effect of under-volting is decreased light output and uncertain starting. Considerable underrunning will also reduce the life since the reduced current through the lamp is not then sufficient to maintain the electrodes at their designed operating temperature. The general effect of over-volting is, of course, to overload the lamp and its auxiliary equipment. Clearly, therefore, to ensure correct and satisfactory operation of the lamp the auxiliary equipment must be adjusted to suit the particular mains voltage concerned.

### (3.6) Effect of Surrounding Air Temperature

The luminous efficiency and the light output of the fluorescent lamp is largely determined by the generation of short-wave ultra-violet radiation set up by an electric discharge through low pressure mercury vapour. The amount of radiation is influenced by the pressure of mercury vapour inside the bulb which in turn is influenced by the atmospheric temperature in which the lamp is operated. The fluorescent lamp is designed to give its normal rated light output when the bulb temperature is about 50. deg. C. This corresponds to a surrounding air temperature of about 20 deg. C. Fig 4 shows the relation between luminous efficiency and ambient temperature for a typical 5 ft. 80 watt lamp (1).

It will be observed that the efficiency rises to 100 per cent. of the optimum up to an ambient of about 20 deg. C. and then gradually falls at still higher temperatures. As the efficiency at freezing point will only be about 60 per cent. of the optimum

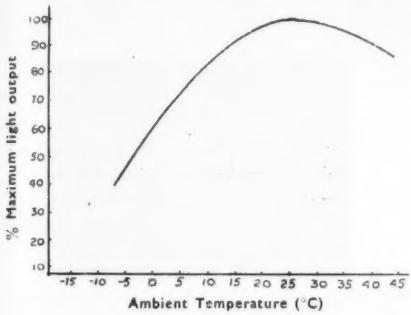



Fig. 4. Relation between luminous efficiency and ambient temperature.

value, the use of a totally enclosed fitting is essential to enable the lamp temperature and light output to build up as soon as possible. In a suitably designed fitting the light output of the lamps should be up to the optimum in less than 10 minutes and up to 70 per cent. of the optimum in about four minutes when the external ambient air temperature is down to freezing point.

In addition to the light output we must also consider the effect of temperature on the electrical characteristics of fluorescent lamps—starting voltage, wattage, etc.—as this will have a considerable bearing on lamp performance.

There is relatively little change in lamp wattage over the temperature range likely to be experienced in practice. The wattage tends to fall as the temperature is reduced, but not more than about 7 per cent. even at temperatures as low as – 10 deg. C. (Fig. 5).

The increase in lamp current with temperature is particularly important for lamps burning in totally enclosed fittings where relatively high ambient temperatures may be experienced. At an ambient temperature of 40-45 deg. C. the lamp current increases about 12 per cent. with a consequent decrease in life of about 15 per cent.

The lamp striking voltage is rather sensitive to change in temperature and, as the temperature is reduced to freezing point, rises about 1 volt for each 1 deg. C. fall in temperature. Fig. 6 shows the temperature-striking voltage relationship for a typical lamp. Thus in an installation where the mains voltage falls to 200 volts at a time

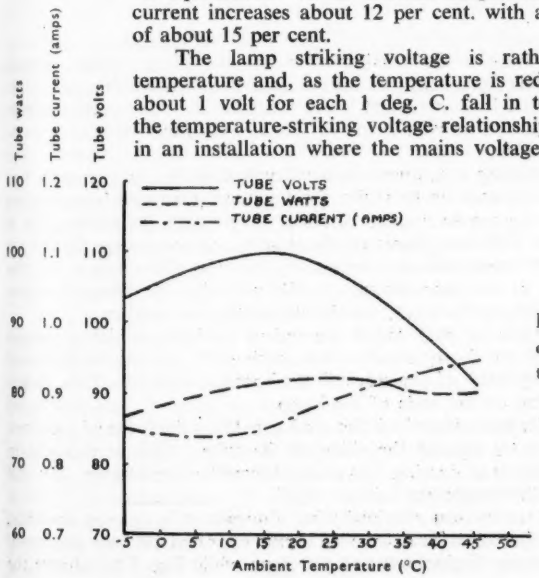



Fig. 5. Variation of lamp volts, current and watts with ambient temperature of 80-watt fluorescent lamp in free air.

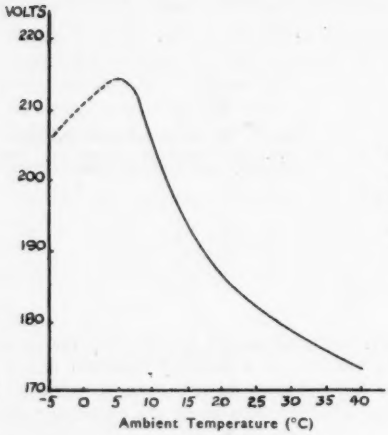



Fig. 6. Variation of starting voltage with ambient temperature of 80-watt fluorescent lamp in free air. (Values of voltage uncertain over this region due to the effect of humidity.)

when the ambient temperature is at freezing point this particular lamp will just start. This figure of mains voltage—200 volts—should be regarded as a minimum for reliable operation at 0 deg. C.

Difficulty in starting at low temperatures may cause repeated flashing of the lamp before starting, with consequent deterioration of the electrodes. Humidity also has some effect on lamp-striking voltage, particularly at extremely low temperatures, and enclosed fittings tending to keep the temperature up to the optimum value and protecting the lamps from draughts and dampness will be an advantage.

### (3.7) Stroboscopic Effect

All discharge-lamps operating in the usual manner on alternating current have a non-uniform light output as the light drops almost to zero with each half cycle, thus causing a periodic flicker, which is increased at lower frequencies. However, the persistence of glow of the fluorescent powder helps to reduce this effect which, in most installations, is hardly noticeable.

In installations where rotating machinery is employed this flicker can give rise to peculiar stroboscopic effects, such as to make the machine gear-wheels appear to rotate at the wrong speed, or even to appear stationary. In such installations it is advisable to operate lamps on different phases of the supply and to arrange that there is an "overlap" of the light from different lamps so that the illumination on the machine never falls to zero at any one instant. Alternatively, the lamps may be operated in the special "twin-lamp" circuit, which is described in section .

A further form of flicker can be observed at the end of the lamp, which is caused by the cathode glow forming on the electrode, once each cycle, giving a flicker at the lamp end of half the frequency of the normal stroboscopic flicker. This flicker is usually obscured by covering up the ends of the lamp.

A flicker effect occasionally occurs in which the discharge takes the form of a narrow cord, which spirals and oscillates against the sides of the tube. This is thought to be due to particles of the electrode coating travelling down the arc stream, but the effect is rarely noticed once the lamps are initially aged.

Fig. 7 (b) shows the light wave-form obtained when fluorescent lamps are operated inductively; Fig. 7 (c) shows the wave-form for two lamps operated on two phases of a three-phase supply with a phase displacement of 120 deg.; while Fig. 7 (d) shows the

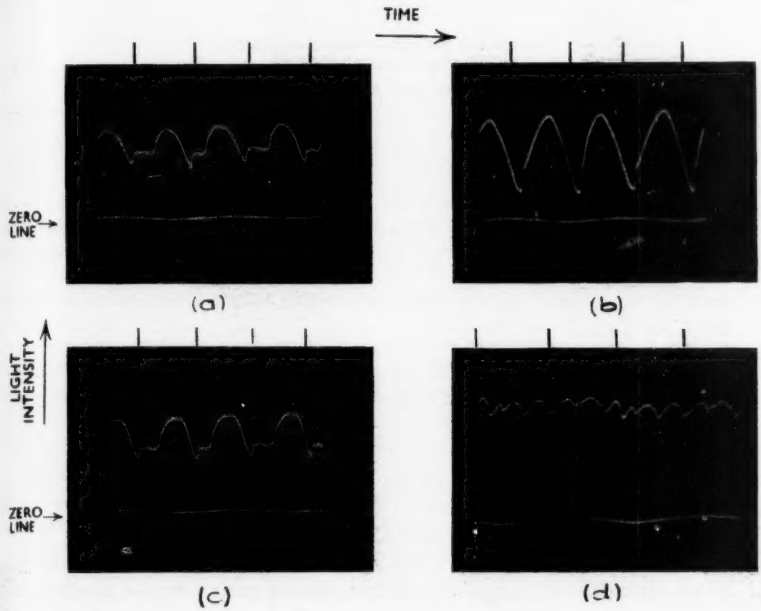



Fig. 7. Variation in light intensity during a cycle of fluorescent lamps. (Marked time interval = 1/100 second.)

variation in intensity of the mixed light from three lamps operated on a three-phase supply. Fig. 7 (a) shows the effect of the "twin-lamp" circuit, the result obtained being about the same as if the tubes were operated from two phases of a normal three-phase supply.

**(3.8) Colour**

Fluorescent lamps are now available in four different colours: daylight, warm white, natural and colour matching. Whilst it is not within the purview of this paper to discuss the application of these different colours, it can be said that they cover almost all requirements of fluorescent lighting. It will be noted from Table 6 that not all ratings of lamps are manufactured in all four colours, the availability of types and colours being suited to the existing demand.

It is generally accepted that the most convenient method of specification of these colours is to indicate the luminosity distribution in eight spectral bands covering the visible spectrum (2). The luminosity distributions for the four colours are given in Fig. 8. These represent "target" objectives, and there may be slight divergencies from lamp to lamp of the same type.

The ultra-violet radiation emitted by the fluorescent lamp falls in the harmless range of wavelengths 4,000 to 3,000 Angstrom units; the amount of ultra-violet energy received by an object even at a short distance from the lamp is less than that received in winter sunlight (Table 7). There is no radiation whatever in the danger zone below 2,800 Angstrom units, because the glass envelope of the lamp absorbs the very short wavelengths. Of course, most of the ultra-violet energy in the lamp is transformed to light of a longer wavelength by the fluorescent powders.

## Table 6.

**Fluorescent Lamps—Colours available.**

| Lamp Wattage | Colours | | | |
|---|---|---|---|---|
| 125/75 | — | — | Natural | — |
| 70/50 | — | — | ,, | — |
| 80 | Daylight | Warm White | ,, | Colour Matching |
| 40 | Daylight | ,, | ,, | — |
| 30 | — | ,, | ,, | — |
| 40 (2 ft.) | — | ,, | ,, | — |
| 20 | — | ,, | ,, | — |
| 15 | — | ,, | ,, | — |

## (4) Circuits and Circuit Operation

The primary requirements of a fluorescent lamp circuit are to operate the lamp at its correct wattage and to provide adequate cathode preheating for starting. The

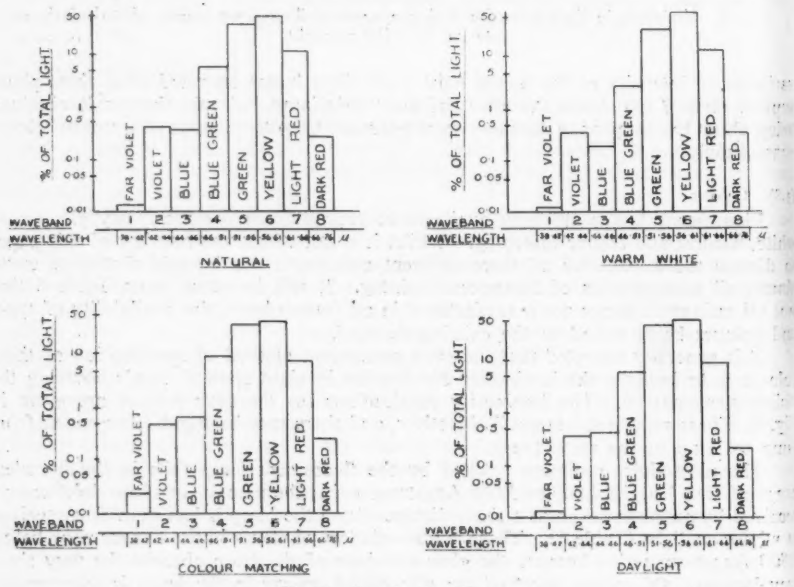



Fig. 8. Luminosity Charts.

**Table 7.**

**U.V. Radiation from Fluorescent Lamps.**

**Approximate values of actual energy in milliwatts per cm².**

| Description of Radiation | Wavelength Region | Noon Sunlight 42° N | | 1 metre from typical 80-watt Fluorescent Lamp |
|---|---|---|---|---|
| | | Summer | Winter | |
| Near U.V. (harmless)... | 4,000–3250 Å | 3.5 | 0.5 | Less than 0.005 |
| Erythemal ... ... | 3,250–2,800 Å | 0.2 | 0.01 | Less than 0.0005 |
| Harmful short-wave U.V. | Below 2,800 Å | None | None | None |

introduction of shorter lamps has required the development of new circuits. Most of the circuits regarded as being standard practice are described in this section.

### (4.1) The Simple Fluorescent Lamp Circuit

The essential components of the simple circuit comprise the lamp, choke and starting switch. In addition, there is usually a radio interference suppression capacitor and a power factor correction capacitor.

Two types of starter switch are in popular use in this country; the glow switch (3), which is a voltage operated device, and the thermal switch (4), which is a current operated device. One type of glow starting switch, Fig. 9 (A), consists of a bi-metallic strip which carries one of the switch contacts and a single fixed contact, enclosed in a small tubular bulb filled with helium gas at low pressure. A more recent pattern is enclosed in a metal canister together with a radio suppression capacitor, Fig. 9 (B). The

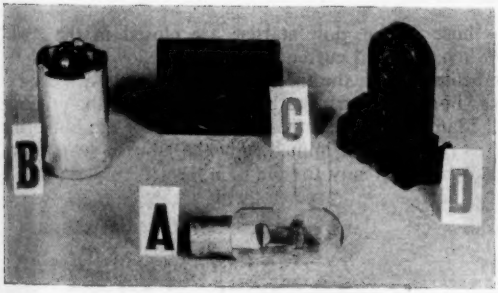



Fig. 9.
Starting switches and sockets.

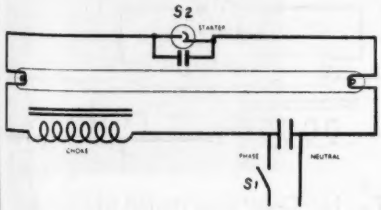



Fig. 10. Circuit of choke-controlled lamp with glow starter.

switch contacts are connected across the two larger contacts on the base, the two smaller contacts being short circuited.

The complete circuit of the simple choke-controlled lamp with glow starters, is shown in Fig. 10: it operates as follows:—

(a) The main switch S.1 is closed. This applies practically full mains voltage to the lamp and to the glow starting switch connected in parallel with the lamp. The mains voltage is insufficient to start the main discharge in the lamp, but the discharge in the helium gas in the glow switch heats the bi-metallic strip, which bends over and makes contact.

(b) The glow switch contacts having closed, the supply circuit is completed through the choke and the lamp electrodes. The current through the electrodes is suitably limited by the choke coil. This current, passing through the electrodes, is sufficient to heat them to incandescence and to start ionisation of the gas in their immediate vicinity.

(c) As the glow switch is now short circuited (the switch contacts being closed) there is no longer any heat from the helium discharge in the switch and therefore the bi-metallic strip cools, thereby opening the switch contacts in a second or two. Breaking the circuit produces a high voltage kick (caused by the collapse of the magnetic field in the choke coil), of about 800/1,000 volts which is sufficient to start the discharge through the lamp. After the lamp discharge has started, the voltage across it is about half the mains voltage, the rest of the supply voltage being taken up by the choke. This voltage is insufficient to start the discharge in the glow switch which remains effectively out of operation until the lamp has to be restarted again.

The glow switch starter circuit is suitable for use with 5-ft. 80-watt, 4-ft. 40-watt and 3-ft. 30-watt lamps.

The thermal or current operated switch which is illustrated in Fig. 11 comprises two bi-metallic strips in close juxtaposition to a heater coil. These elements are housed in a glass bulb, which is enclosed in a metal can together with the radio suppression capacitor. The heater coil is connected across the two narrow diameter contacts and the switch contacts across the two larger diameter pins. The simple thermal switch circuit is shown in Fig. 12.

The switch contacts, unlike those in the glow starter, are closed in the "off" position so that when the main switch is closed current immediately flows through the lamp electrodes, and through the heater coil in the thermal switch. After a second or so the heat from this coil causes the bi-metallic strips to break contact and the inductive surge from the choke coil starts the lamp. The heat from the coil keeps the bi-metallic strips apart all the time the lamp is running, but immediately the lamp is switched off the bi-metallic strips cool and make contact ready for the next "start."

Fig. 11. Thermal type switch.

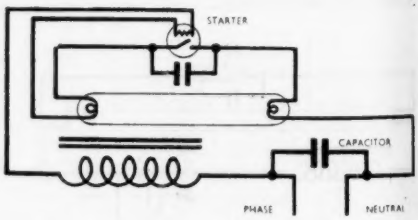



Fig. 12. Circuit using thermal type switch.

The thermal switch circuit is applicable to all sizes of fluorescent lamp, operated singly or in series as described later. Thermal switches of different current ratings are available.

### (4.2) Twin-lamp Circuit

A further development in fluorescent lamp circuits is the "Twin Lamp" circuit(s) illustrated in Fig. 13, in which one lamp is operated in the normal way, in series with

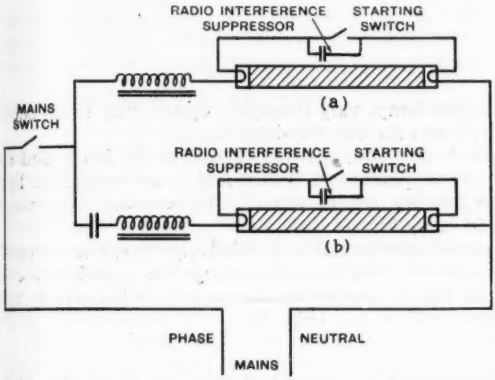
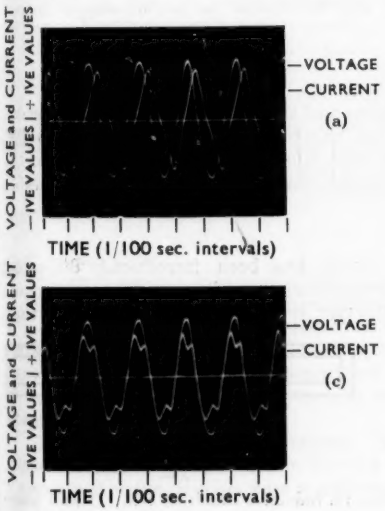



Fig. 13.
Twin-lamp circuit.

a choke coil, and the other in series with a capacitor and choke coil. The circuit with the choke alone in series has a power factor some 60 deg. lagging and that with the choke and series condenser a power factor some 60 deg. leading. The resultant power factor of the twin lamp circuit is practically unity.

Fig. 14 (a) and (b) show the way in which the mains voltage and lamp current for



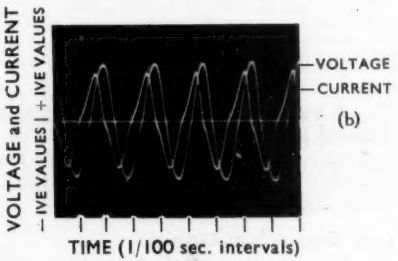




Fig. 14.
Oscillograms showing voltage-current waveforms of twin-lamp circuit.

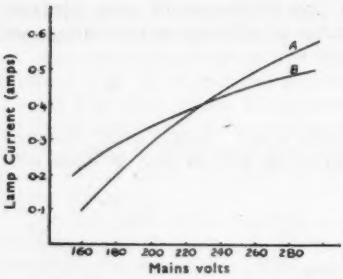



Fig. 15. Relation between mains voltage and lamp current of inductively and capacitively controlled lamps. (A :— 4-ft. 40-watt lamp on inductive circuit. B :— 4-ft. 40-watt lamp on capacitively controlled lamps.)

inductively and capacitively controlled lamps vary through a cycle. Fig. 14 (c) shows the mains voltage and combined current for the twin-lamp circuit.

As the light from each lamp is in phase with the current in the lamp, and the current in one lamp is 120 deg. out of phase with the current in the other, the light from the two lamps will also be 120 deg. out of phase. The resultant "smoothing out" of light is considerable as shown by Fig. 7a.

A further advantage of the capacitative circuit is its relatively "constant current" characteristic. Thus, if there is a sudden drop in mains voltage the capacitively controlled lamp is much more likely to remain alight than one controlled inductively, and also the depreciation in light output will be less (Fig. 15).

### (4·3) Series Operation

As previously mentioned, the relatively low lamp voltage of the 24 in. and 18 in. lamps renders them suitable for series operation on 200/250 volt supplies from a single set of control gear. The circuit for two such lamps inductively controlled is illustrated in Fig. 16.

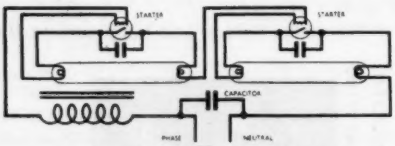



Fig. 16. Circuit for two fluorescent lamps in series.

A starter is required for each separate lamp and the thermal-type starter is recommended because the normal glow starter is not suitable for voltages much below 200, and only half this voltage is available across each lamp when lamps are operated two in series. The current rating of the thermal switch must be suited to the current rating of the lamps.

### (4·4) Instant-Start Circuits

Recently the so-called "instant-start" circuit has been introduced, dispensing with a starter but using a cathode heating transformer in addition to the usual choke coil (Fig. 17). The cathode heating transformer is autowound and gives a slight

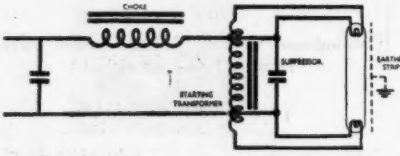



Fig. 17. Instant-start circuit.

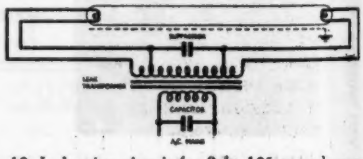



Fig. 18. Inductive circuit for 8-ft. 125-watt lamps.

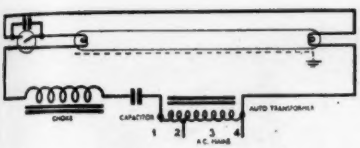



Fig. 19. Capacitively controlled circuit.

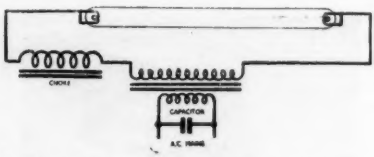



Fig. 20. Circuit for 8-ft. 70-watt lamps.

voltage step-up in addition to providing the requisite cathode heating current. This, combined with the special " instant-start " lamp which has an earth strip fixed along its exterior provides reliable and relatively quick starting.

### (4.5) Circuits for 8-ft. Lamps

The 8-ft. 125-watt lamp can be operated on inductive or capacitive circuits, and because of the relatively high-lamp voltage some mains voltage step-up is necessary on most supplies. Fig. 18 shows the inductive circuit utilising a step-up transformer of the leakage reactance pattern and providing a cathode heating in a similar manner to the " instant-start " transformer already described. The regulation characteristics of this transformer dispense with the normal choke coil and no starter is necessary. The circuit is shown with a power-factor correction capacitor which is, of course, omitted if it is to be used in conjunction with a capacitative circuit to obtain the advantages of the " twin lamp " arrangement.

The capacitively controlled circuit is shown in Fig. 19 and comprises a standard 50-watt choke and series capacitor, and a small step-up transformer for supply voltages from 200 to 240. On 250 volt supplies this transformer is not necessary.

It will be noted that, with the capacitive circuit a thermal-type starter is used. To facilitate starting, the 8-ft. 125-watt lamp is fitted with a metallic strip similar to the 5-ft. 80-watt " instant-start " lamp. The 125-watt lamp may also be operated at 75 watts using an inductive instant-start-type transformer of suitable design.

The 8-ft. 70-watt lamp is one inch in diameter and operates on the circuit illustrated in Fig. 20 which comprises a choke and tightly wound step-up transformer. No starting switch is necessary. The 8-ft. 70-watt lamp may also be operated at 50 watts using similar auxiliary gear.

## (5) Auxiliary Gear

As previously mentioned, the essential components of the simple fluorescent-lamp circuit, are the choke, capacitor and starter switch; but instant-start circuits and circuits for the 8-ft. lamps introduce several types of transformers which must be considered, as well as the various types of capacitors for power-factor correction and for radio interference suppression.

### (5.1) Choke Coils

Mercury vapour, in common with other gases, has a " negative " resistance because, as the current through the lamp increases, greater ionisation of the gas occurs which, in turn results in a still lower resistance, unlike metal filaments in which an increased current through the wire results in an increased resistance. Thus, the fluorescent lamp must be operated in series with some form of limiting impedence of which an inductance or " choke " coil, as it is more generally termed, is most convenient and economical on alternating current.

In addition to being a " current limiter," the choke must have several other important characteristics. While limiting the normal operating current of the lamp to a prescribed value, it must pass a sufficiently high current through the lamp electrodes

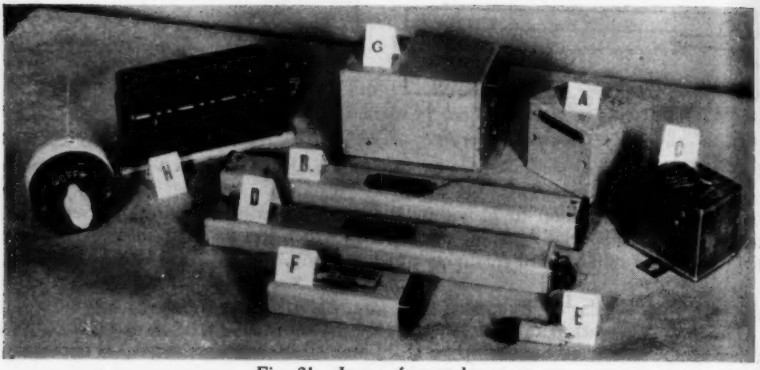



Fig. 21. Items of control gear.

## Table 8.
### Gear Losses in Various Lamp Circuits.

| Lamp | Voltage Range | Circuit Arrangements | Choke Consumption (Watts) |
|---|---|---|---|
| 8 ft. 125 | 200/250 | Single | 35 |
| 8 ft. 75 | ,, | ,, | — |
| 8 ft. 70 | ,, | ,, | 20 |
| 8 ft. 50 | ,, | ,, | — |
| 5 ft. 80 | ,, | ,, | 20 |
| 4 ft. 40 | ,, | ,, | 10 |
| 3 ft. 30 | ,, | ,, | 7 |
| 2 ft. 40 | ,, | Two-in-series | 20 |
| 2 ft. 40 | 100/130 | Single | 10 |
| 2 ft. 20 | ,, | ,, | 5 |
| 2 ft. 20 | 200/250 | ,, | 10 |
| 2 ft. 20 | ,, | Two-in-series | 10 |
| 1½ ft. 15 | ,, | ,, | 7 |
| 1½ ft. 15 | ,, | Single | 10 |
| 1½ ft. 15 | 100/130 | ,, | 5 |

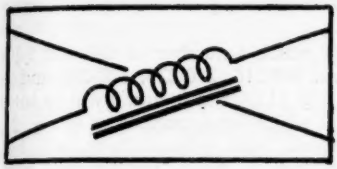


Fig. 22. Internal wiring of elongated choke.

for adequate preheating. It must also ensure that the current in the circuit is not seriously affected by momentary fluctuations of supply voltage, and it must have a reasonably low wattage loss. Furthermore, the choke must have a satisfactory operating temperature and a low-noise level.

Chokes embodying these characteristics are manufactured in elongated shape for use with all ratings of lamps already mentioned and

**Table 9 (a).**
**Capacitors for Power Factor Correction.**

| Mains Volts | Lamp | | Capacitor Capacity in MFD | Type | Approx. P.F. | Circuit |
|---|---|---|---|---|---|---|
| | Size in ft. | Wattage | | | | |
| 200/210 | 8 (1½ in.) diam. | 125 | 20 | Cubic | 0.9 | Single |
| 220/230 | 8 (1½ in.) diam. | 125 | 15 | ,, | 0.9 | ,, |
| 240/250 | 8 (1½ in.) diam. | 125 | 15 | ,, | 0.95 | ,, |
| 200/210 | 8 (1½ in.) diam. | 75 | 10 | ,, | 0.9 | ,, |
| 220/230 | 8 (1½ in.) diam. | 75 | 7.5 | Cubic or long | 0.85 | ,, |
| 240/250 | 8 (1½ in.) diam. | 75 | 7.5 | ,, | 0.9 | ,, |
| 200/250 | 8 (1½ in.) diam. | 70 | 15 | Cubic | 0.9 | ,, |
| 200/250 | 8 (1½ in.) diam. | 50 | 10 | ,, | 0.9 | ,, |
| 200/250 | 5 (1½ in.) diam. | 80 | 7.5 | Cubic or long | 0.85 | ,, |
| 200/250 | 4 (1½ in.) diam. | 40 | 3.25 | Long | 0.85 | ,, |
| 200/250 | 3 (1 in.) diam. | 30 | 3.25 | ,, | 0.85 | ,, |
| 200/250 | 2 (1½ in.) diam. | 40 | 7.5 | ,, | 0.85 | Two-in-series |
| 200/250 | 2 (1½ in.) diam. | 20 | 3.25 | ,, | 0.85 | ,, |
| 200/250 | 2 (1½ in.) diam. | 20 | 4.5 | ,, | 0.85 | Single |
| 105/120 | 2 (1½ in.) diam. | 20 | 5 | ,, | 0.85 | ,, |
| 200/250 | 1½ (1 in.) diam. | 15 | 3.25 | ,, | 0.85 | Two-in-series |
| 200/250 | 1½ (1 in.) diam. | 15 | 4.5 | ,, | 0.85 | Single |
| 105/120 | 1½ (1 in.) diam. | 15 | 5 | ,, | 0.85 | ,, |

in cubic shape for use with the 80-watt lamp Both are compound-filled to eliminate choke hum so far as possible.

All chokes are of the fixed voltage pattern of which a number of different types cover the voltage range 100-120 and 200-250, thus 200/210, 210/220, 220/230 and so on. Cubic- and long-type chokes are illustrated in Fig. 21 (A and B) and it will be noted that the long-type choke has four terminals, two of which are connected as in Fig. 22, the "through lead" facilitating fittings wiring (some later patterns have only two terminals at one end). The approximate wattage loss in chokes for different lamp arrangements is given in Table 8. The loss in the elongated-type choke is somewhat more than that of the cubic-type due to its core shape.

### (5.2) Capacitors

Capacitors, like chokes, are made in both cubic and elongated forms, and for ordinary parallel-connected power-factor correction, or for series-operation in capacitive circuits. The cubic-type capacitor is restricted to the 80-watt circuit only.

**Table 9 (b).**

**Series Capacitors for Capacitive Circuits.**

| Mains Volts | Lamp | | Capacitor | | Approx. P.F. | Circuit |
|---|---|---|---|---|---|---|
| | Size in ft. | Wattage | Capacity in in MFD. | Type | | |
| 200/250 | 8 (1½ in.) diam. | 125 | 7 | Cubic or long | | Single |
| ,, | 5 (1½ in.) diam. | 80 | 7 | ,, | 0.5 leading | ,, |
| ,, | 4 (1½ in.) diam. | 40 | 3.25 | Long | ,, | ,, |
| ,, | 3 (1½ in.) diam. | 30 | 2.7 | ,, | ,, | ,, |
| ,, | 2 | 40 | 7 | ,, | ,, | Two-in-series |
| ,, | 2 | 20 | 3.25 | ,, | ,, | Two-in-series |
| ,, | 2 | 20 | 2.7 | ,, | ,, | Single |
| ,, | 1½ | 15 | 2.7 | ,, | ,, | Two-in-series |
| ,, | 1½ | 15 | 2.7 | ,, | ,, | Single |

long capacitors are available for all circuits. Larger capacitors for group correction of two or more lamps are also manufactured. Cubic and long-type capacitors are illustrated in Fig. 21 (C and D).

The long capacitors for series operation are considerably longer than those used for parallel correction, as the voltage developed across them in the capacitive circuit may be as high as 350, and additional internal insulation must be provided.

Tables 9 (a) and (b) give the recommended values of capacitors for the various types of circuits already discussed.

For the suppression of radio interference a small capacitor of 0.02 mfs. is connected across the lamp. In the modern-pattern starter this capacitor is incorporated

in the starter-canister, but in older fittings it is a separate unit. It is illustrated in Fig. 21 (E).

### (5.3) Starter Switches

Starter switches are made in two principal types—glow and thermal, as already mentioned and previously illustrated. The early-pattern glow-switch made for the 80-watt lamp only had a standard SBC two-contact cap, and is supplied in two voltage ranges, 200/220 and 230/250. The present standard, glow or thermal, starter-switch is housed in a four-contact canister, which also incorporates the radio-suppression capacitor. Incorrect fitting of the starter in its appropriate socket is prevented by making two of the diagonal cup pins and the two corresponding socket contacts of a larger size (Fig. 9 (c)), which shows the four-contact socket.

In the glow-type canister-switch, the switch is always connected across the large contacts, the two smaller-diameter contacts being short-circuited inside the canister.

In the thermal-type canister-switch the switch contacts are also connected across the large diameter contacts and the heater coil across the two smaller ones. The starter socket has a short-circuiting device across the contacts BB, which comes into

**Table 10.**

**Starter Switches for Use with Different Sizes of Lamps.**

| Lamp | Mains Volts | Type of Starter |
|---|---|---|
| 125 w. (capacitive) ... ... | 200/250 | Thermal |
| 80 w. ... ... ... | 200/220 AC | 200/220 Glow } or |
| ,, ... ... ... | 230/250 AC | 230/250 Glow } thermal |
| ,, ... ... ... | 200/250 DC | Thermal |
| 40 w. ... ... ... | 200/220 AC | 200/220 Glow } or |
| ,, ... ... ... | 230/250 AC | 230/250 Glow } thermal |
| ,, ... ... ... | 200/250 DC | Thermal |
| 30 w ... ... ... | 200/220 AC | 200/220 Glow } or |
| ,, ... ... ... | 230/250 AC | 230/250 Glow } thermal |
| ,, ... ... ... | 200/250 DC | Thermal |
| 40 w. 3 ft. ... ... ... | 200/250 A } | Each lamp has one thermal |
| ,, ... ... ... | 200/230 DC } | starter |
| ,, ... ... ... | 100/130 AC } | Thermal |
| ,, ... ... ... | 100/130 DC } | ,, |
| 20 w. ... ... ... | 200/250 AC } | Each lamp has one thermal |
| ,, ... ... ... | 200/250 DC } | starter |
| ,, ... ... ... | 100/130 AC } | Thermal |
| ,, ... ... ... | 100/130 DC } | ,, |
| 15 w. ... ... ... | 200/250 AC } | Each lamp has one thermal |
| ,, ... ... ... | 200/250 DC } | starter |
| ,, ... ... ... | 100/130 AC } | Thermal |
| ,, ... ... ... | 100/130 DC } | ,, |

operation when the starter is withdrawn, thus maintaining the circuit and keeping the lamp alight if it is desired to remove the starter.

The standard canister ensures that, if the circuit is appropriately wired, the glow and thermal starters will be electrically and mechanically interchangeable; it must be remembered, however, that for certain purposes (for example, with two lamps operated in series) only thermal starters must be used.

In the glow-type canister-switch two voltage ranges, 200/220 and 230/250, are generally supplied, and two distinct types cover the 3-ft. 30-watt, 4-ft. 40-watt and 5-ft. 80-watt lamps. Several different ratings of thermal switch cover the complete

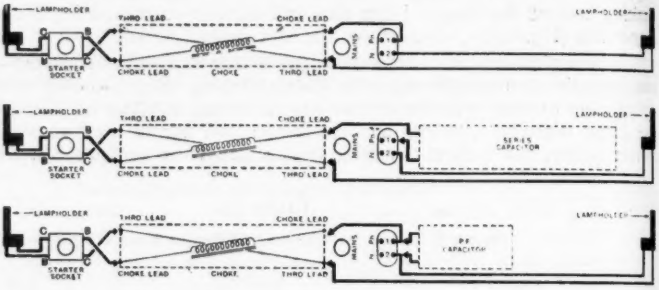



Fig. 23. Practical wiring diagrams of inductively and capacitively controlled lamps.

range of 18-in. to 5-ft. lamps, as the current rating of the thermal switch heater coil must clearly be suited to the current taken by the particular lamp with which it is associated.

Table 10 gives the switch types suitable for operating the various sizes of fluorescent lamps on the different circuits already described. Fig. 23 shows the method of wiring the starter socket in the three standard forms of circuit. A, inductive; B, capacitive; and C, normal parallel PF correction.

### (5.4) Chokes and Capacitors for Twin-lamp Circuit

In the inductive branch of the "twin-lamp" circuit the choke voltage must be suited to the mains voltage. In the capacitive branch, however, because the same capacitor is used for all mains voltages from 200/250 for a given lamp, the voltage of the choke may not exactly correspond with the mains voltage. Table 11 shows the

**Table 11.**

**Rating of Choke Coils for 40 w. and 80 w. Twin Lamp Circuits.**

| Mains Voltage | Inductive Circuit | Capacitive Circuit |
|---|---|---|
| 200/210 | 200/210 | 240/250 |
| 210/220 | 210/220 | 230/240 |
| 220/230 | 220/230 | 220/230 |
| 230/240 | 230/240 | 210/220 |
| 240/250 | 240/250 | 200/210 |

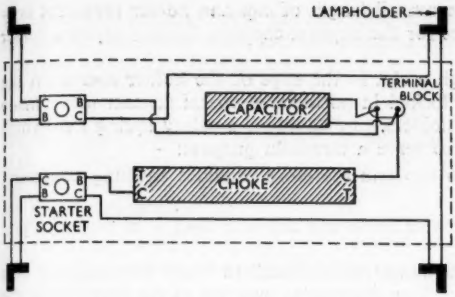



Fig. 24. Practical wiring diagram for series operated lamps.

particular chokes for use with 4-ft. 40-watt and 5-ft 80-watt lamps operating inductively and capacitively at different mains voltages.

**(5.5) Gear for Series Operation**

When 18-in. and 24-in. lamps are operated two in series on 200/250 volt mains, each lamp requires a separate thermal starter switch whose heater current rating corresponds to the lamp running current. Thus two 24-in. 40-watt lamps can be operated in series on 200/250 mains with an 80-watt choke and using two 80-watt thermal starters. A practical wiring diagram is shown on Fig. 24.

Again, two 24-in. 20-watt lamps can be operated in series with a single 40-watt choke and using two 40-watt thermal starters. Since the lamp operating voltage of two short lamps is rather more than double that of a single lamp of twice the length, the particular voltage of choke for use with the series arrangement may not correspond to a given mains voltage. In such cases manufacturers' recommendations should be followed. It should be added that two lamps in series can be operated capacitively as well as inductively.

**(5.6) Gear for Instant Start Circuit**

At present the instant start circuit is chiefly confined to the 5-ft. 80-watt lamp on 220/250 volts and it must be stressed that this circuit should only be used with lamps having an earthed starting wire in close proximity to the wall of the lamp. The circuit has already been described, and the instant start transformer is illustrated in Fig. 21(F). Using standard chokes the lamp is operated at about 10 per cent. less than the nominal 80 watts with a corresponding reduction in light output. Additional gear losses make the power taken from the supply about the same as in the standard circuit.

**(5.7) Gear for 8-ft. 125-Watt Lamps**

As previously mentioned the 8-ft. 125-watt lamp may be operated on inductive or capacitive circuits. With the former a leakage reactance transformer with instant start windings is used and no starter is necessary (Fig. 21(G)). Three voltage ratings of transformer are available, 200/210, 230/240 and 250 volts. The 8-ft. 125-watt lamp has a starting strip similar to the 5-ft. 80-watt instant start lamp. As no canister starter with its incorporated radio interference suppressor is used, an additional suppressor already illustrated in Fig. 21(E) must be fitted.

The capacitive circuit utilises the standard 80-watt choke and series capacitor but an additional step-up transformer is required on mains voltages between 200 and 240. An 80-watt type thermal starter is required and must have special time characteristics to provide adequate electrode preheating.

**(5.8) Gear for 8-ft. 70-Watt Lamps**

The gear for the 8-ft. 70-watt 1-in. lamp comprises a choke and step-up transformer. The lamps may also be operated at 50 watts with similar equipment.

**(5.9) Bi-pin Holders**

The 4-ft. 40-watt and shorter lamps are fitted with the bi-pin cap which, when used in conjunction with the bi-pin holder illustrated in Fig. 9(D), provides an exceed-

ingly compact method of fixing. The overall length of cap and holder measures only about an inch compared with 2¼ inches for the bayonet cap and floating bayonet holder used with the 5-ft. 80-watt lamp.

The cap pins are inserted through a slot in the edge of the holder and when the lamp is rotated through 90 deg. it is locked in position, electrical contact being made by two metallic spring strips in the holders. In addition, a safety spring clip which is used with each holder is designed to serve a threefold purpose:—

(a) It clips around the lamp cap and therefore provides earthing continuity to the fitting.

(b) Should the lamp cap become loose the clip will hold it in position, preventing the lamp from falling.

(c) When fitting bi-pin capped lamps, it is difficult to insert the lamp cap pins into both holders simultaneously. The clip retains one end of the lamp while the other is being positioned, before turning the lamp through 90 deg. to its final working position.

The overall length of the 4-ft. and shorter lamps is actually slightly less than the nominal length which includes the width of the bi-pin holders.

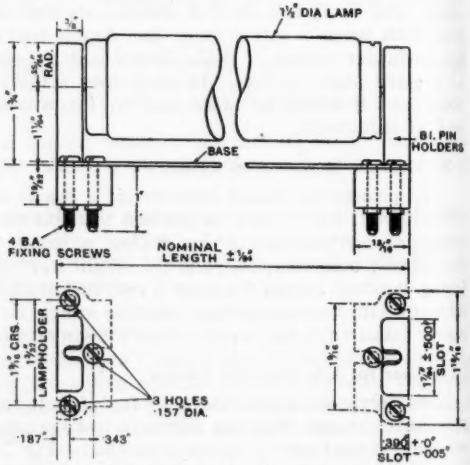



Fig. 25. Mounting position for bi-pin lamp holders.

Because the dimensions of the cap pins and bi-pin holder are necessarily small, the lamp holders should be mounted within ± 1/64th inch of the normal lamp length. Full particulars of holder dimensions and mounting position are given in Fig. 25.

## (6) D.C. Operation

When fluorescent lamps are used on a direct current supply a resistance of the correct value and rating must be connected in series with each lamp. In addition a choke, starter, and radio interference suppressor as recommended, will be required and each lamp or group of lamps must be fitted with polarity reversing arrangements. The latter may, conveniently, be a reversing switch controlling the supply to the lamps so that each time the supply is switched on the polarity of the lamp electrodes is changed. The purpose of this polarity reversal is to counteract the tendency on direct current, of the mercury vapour to accumulate at one end of the lamp, with consequent reduction of light output at the other end. Normal switching on and off will generally suffice to

overcome this trouble, but if the dark-end effect shows itself during a period of use it will correct itself after operation of the mains reversing switch. A typical resistance and reversing switch are illustrated in Fig. 21(H).

Starting is more difficult on D.C. than on A.C. and may be uncertain on supply voltages below 220v. D.C. Stroboscopic flicker and power factor correction problems are, of course, absent. The life of the lamps is not likely to be adversely affected by D.C. operation and although colour and total light output are the same as on A.C. the overall luminous efficiency is considerably reduced owing to the wattage lost in the series resistance.

**Table 12.**

**Resistance Values for DC Operation of Fluorescent Lamps in Ohms.**

| Mains Volts | 5 ft. 80 w. | 4 ft. 40 w. | 3 ft. 30 w. | 2 ft. 40 w.* | 2 ft. 20 w.* | 18 in. 15 w.* |
|---|---|---|---|---|---|---|
| 200/210 | 116 | 210 | 276 | 121 | 183 | 245 |
| 220/230 | 147 | 275 | 338 | 147 | 245 | 308 |
| 240/250 | 175 | 330 | 399 | 175 | 308 | 368 |

* Two lamps in series.

The thermal-type starter-switch is recommended for D.C. operation, and the values of the resistance for different mains voltages are given in Table 12. The circuit arrangement is illustrated in Fig. 26.

## (7) Radio Interference

Electric discharges tend to generate high frequency oscillations which may cause radio interference (6) either by direct radiation from the lamp and its associated wiring, or by "feedback" through the supply leads. Generally speaking, this interference is only noticeable when the radio receiver is in fairly close proximity to the lamp itself. The broadcast wavelengths 200 to 500 metres are most affected. Usually, interference on short waves is not objectionable, being confined to relatively small sections of the short-wave broadcast band. It is usual to shunt the tube by a small 0.02 mfd. capacitor which is generally sufficient to suppress the radio interference. Generally speaking, an old lamp is more likely to cause trouble than a new one.

Interference caused by radiation from the wiring is much less likely to occur than direct interference from the lamp, particularly as the wiring and mains are generally shielded in an earthed metal fitting and conduit. Should interference be objectionable, the following procedure should be adopted:—

(a) Make sure that the interference suppression capacitor is fitted and properly connected.

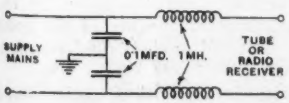



Fig. 26. Circuit for lamps on D.C.

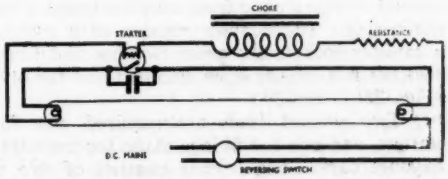



Fig. 27. Typical filter for radio interference suppression.

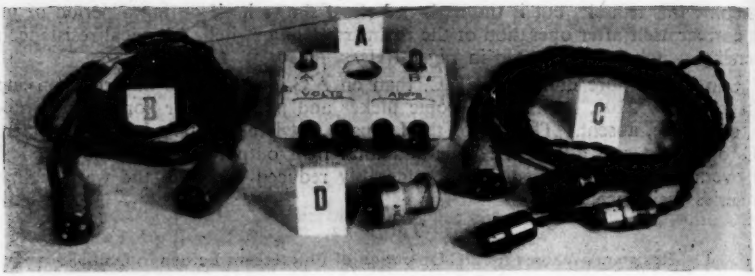



Fig. 28. Equipment for testing fluorescent lamp circuits.

(b) If this is in order, make sure that the capacitor itself is not faulty, preferably by substituting a different capacitor from some other fitting which does not give rise to interference.

(c) If the trouble still exists; with an 80-watt lamp, reverse the B.C. lampholder at one end of the tube, and if still present, reverse the lampholder at the other end; with lamps with bi-pin caps, reverse the connections to the individual bi-pin lampholders.

Should the above adjustment fail to eliminate the interference, one must determine whether it is coming direct from the lamp or if it is being transmitted through the mains. This can be ascertained by interposing an earthed sheet of metal between the lamp and aerial of the receiver, and as close to the lamp as possible. If the interference is now eliminated it is obvious that it is emanating from the lamp itself, and a permanent earthed wire mesh of about 1 in. section should be placed over the mouth of the fitting.

If interference is still prevalent, it is most probably due to direct feed-back through the supply mains and it will be necessary to fit a mains filter either in the lamp or receiver supply leads, preferably the former. There are many different varieties of mains filter unit, one of the simplest being illustrated in Fig. 27. It consists of two 0.1 mfd. condensers connected across the mains, with the centre point earthed, and a high-frequency choke of 1 mh. inductance in each mains load. Each choke must be capable of carrying the full receiver current.

## (8) Testing Fluorescent Lamp Circuits

The satisfactory operation of a fluorescent lamp is clearly dependent on its operating under the conditions for which it was designed. If the appropriate choke coil is used for the average mains voltage concerned, the lamp should consume a power very close to the rated lamp wattage; this can be derived from the product of lamp volts, current and a form factor of approximately 0.9.

The starting and running conditions of fluorescent lamps and control gear under normal working conditions may be tested with a simple adaptor without alteration to the wiring. The adaptor consists of a switch block approximately 5½ in. × 3½ in., a canister socket, two press switches and four insulated terminals. One of the press switches is normally open-circuited and the other short-circuited in the "off" position. (Figs. 28(A) and 29.)

Two sets of leads are required, one for use with fittings using canister-type starters, and one for fittings made for use with the S.B.C. glow starter and lamps with bayonet caps. The former consists of two canister starters with the switches and radio suppression capacitors removed. (Figs. 28(B) and 30). For testing 80-watt lamps

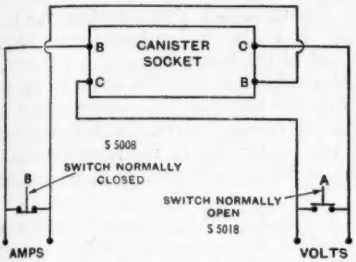



Fig. 29 *(above)*. Wiring of test adaptor.

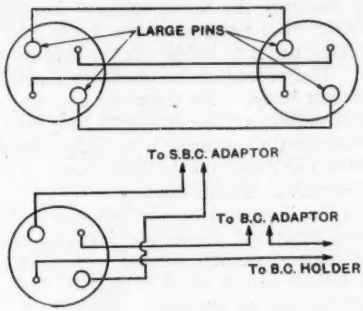



Fig. 31.
Wiring of test-lead for S.B.C. glow starter.

Fig. 30 *(top right)*. Wiring of canister test-lead.

with bayonet caps and S.B.C. glow starters, the lead consists of a canister starter with switch and radio suppression capacitor removed, B.C. and S.B.C. adaptors and B.C. holder. (Figs. 28(C) and 31.)

It will be seen from Fig. 29 that the function of the press switch "A" which is normally open, is to short circuit the usual glow starter switch contacts: when pressed and released after a few seconds the switch acts as a "manual" starter and strikes the lamp. The press button switch "B" is connected across the ammeter and is normally closed. It must, therefore, be depressed for current readings to be taken and acts as a safety shunt to the meter as well as completing the circuit when the meter is not connected.

To measure the operating characteristics of a 40-watt lamp, the test canister at one end of the test lead is inserted into the socket on the adaptor panel and the canister at the other end is inserted in the starter socket in the fitting; the lamp being in place in the fitting but the normal starter being removed. Readings are taken as follows:—

*Mains Volts.* When the mains are first switched on to the fitting a voltmeter connected across the volt terminals on the test panel will register mains volts.

Fig. 32. Improved composite test set.

*Lamp Volts.* If switch "A" is pressed and then released after about two seconds the lamp should strike and the voltmeter will then register the voltage actually across the lamp.

*Starting Current.* If switch "B" is pressed at the same time as switch "A," an ammeter connected between the amps. terminals on the test panel will register the lamp starting current.

*Running Current.* When the lamp is running, the running current may be read on the ammeter by pressing switch "B" alone.

The second set of leads, for use with the 80-watt lamps with bayonet caps and glow starters with S.B.C. caps, is used similarly. Connection at the fitting end is made

by inserting the S.B.C. adaptor into the S.B.C. starter socket, disconnecting the B.C. holder from one end of the lamp and inserting in it the B.C. adaptor, and finally placing the B.C. holder on the lead on the free end of the lamp.

The procedure for measuring the lamp characteristics is then the same as for the 40-watt lamp. As there are two ways of putting the test lead B.C. adaptor into the lamp holder on the fitting, it may be found that no running current is indicated. In this case the ammeter is actually connected on the starter side of the lamp instead of being connected on the mains side of the lamp and the B.C. adaptor must be reversed to obtain a current reading.

An improved type of adaptor is illustrated in Fig. 32. This is constructed on the lines described above but includes the refinement of a change-over switch for volt or ampere readings for use with a universal meter. It also has several different types of starter socket wired in parallel with the four-way lead so that various starters may be tried out on the bench without the necessity of climbing up and down to the fitting under test.

The approximate lamp operating characteristics for all ratings of lamps in inductively controlled circuits have been given in Table 4. In capacitatively controlled circuits the lamp starting current is materially the same as the lamp running current. It must be remembered that the lamp takes a few minutes to achieve complete stability, particularly if the ambient temperature is low.

The power factor of an uncorrected lamp circuit, due to the inductance of the choke coil, is approximately 0.5; the lamp and mains current will be as quoted in Table 4. When the power factor is corrected by means of the recommended capacitor the lamp current will be unaltered, but the mains current will be reduced. (See Table 7.)

Where the lamp attempts to strike but will not remain alight it is helpful to know the operating conditions as the fault may be due to (1) low mains voltage; (2) correct mains voltage but abnormally low lamp current due to incorrect gear; (3) faulty starter switch, or (4) faulty lamp. (1), (2), and (3) may be checked by the method described above.

If the lamp has failed by passing excessive current, it is inadvisable to install a new lamp before checking the circuit conditions. This is done by short circuiting the two lamp holders in the fitting concerned and measuring: (a) the short circuit current of the choke coil; (b) the voltage across the starting switch. Convenient adaptors for short circuiting the lamp holders can be made from (a) B.C. adaptors for use with 5-ft. 30-watt lamps, or (b) bi-pin caps short circuited between the pins and mounted as in Fig. 28(D) for the 4-ft. 40-watt and shorter lamps.

The short circuit current should not materially exceed the rated starting current of the lamp: if it does, or if the circuit fuse is blown, there is probably a fault in the choke coil or an earth fault in the wiring. If the voltage across the starting switch is greater than the mains voltage, the power factor capacitor is connected across the lamp and not across the mains, thus forming a partially resonant circuit. If there is no reading on the voltmeter there is probably an open circuit which may be due to (1) a disconnection in the wiring, or (2) a broken lamp electrode.

## (9) Servicing

### (9.1) General

Although the servicing of a fluorescent lamp installation is not quite as simple as that of a tungsten lamp installation, it should present no serious difficulties. Minor faults in the circuit and control gear sometimes occur but the only likely difficulties—namely those due to the mains voltage, ambient temperature, the lamp itself, its control gear or some mal-adjustment thereof—are those described in this paper. Generally speaking such faults are comparatively simple to trace and remedy.

A circuit which is not operating normally should be disconnected from the supply

until the defect can be remedied; if several lamps are operating from the same main circuit switch, the lamp should be removed from the defective unit and this particular circuit locally isolated. A new lamp should not be tried in a circuit which has been operating abnormally unless it has been established that the circuit itself is not faulty or until the original fault has been rectified.

Abnormal operation under low ambient temperature conditions has already been mentioned in section 3.6, but trouble from this cause alone is unlikely as low-mains voltage often (and unfortunately) coincides with temperature fall. As the mains voltage falls, the current through the lamp falls and the voltage across the lamp rises. If the lamp is operated by a glow-type starter in these conditions the voltage across the lamp and starter may rise sufficiently to cause the starter to close thus extinguishing the lamp or preventing it striking when first switched on. Alternatively, if a thermal-type starter is being used, the reduction in lamp current arising from an abnormal mains voltage may cause the starting-switch contacts to close. It is also possible, that the reduced lamp current will be insufficient to keep the electrodes up to temperature for stable operation apart from irregular operation of the starter switch.

Assuming that the external conditions are sensibly normal, a lamp may (a) attempt to strike, (b) glow continuously at the ends, or (c) may not attempt to strike at all. The possible sources of trouble in the three cases are tabulated in Tables 13 (a), (b) and (c).

Table 13 (a)

Lamp attempts to strike:—

| | | |
|---|---|---|
| (a) Lamp | (i) | Life expired. |
| | (ii) | Faulty lamp. |
| (b) Starter switch | (i) | Contacts break too quickly (glow or thermal type). |
| | (ii) | Low extinguishing voltage (glow type). |
| | (iii) | Incorrect voltage starter (glow type). |
| | (iv) | Incorrect rating of starter (thermal type). |
| (c) Control gear | (i) | Incorrect choke or choke tapping. |
| | (ii) | Incorrect capacitor in T.L. circuit. |
| (d) Wiring | (i) | Heater coil and switch contacts of thermal-type starter reversed. |

Table 13 (b)

Lamp will not strike:—

| | | |
|---|---|---|
| (a) Lamp | (i) | Broken electrode. |
| | (ii) | Cracked tube. |
| | (iii) | Faulty lamp. |
| (b) Starter switch | (i) | High-striking voltage (glow type). |
| | (ii) | Broken bi-metal (glow or thermal type). |
| | (iii) | Cracked bulb. |
| | (iv) | Open circuit in heater coil (thermal type). |
| | (v) | Switch contacts will not close (thermal type). |
| | (vi) | Short-circuited contacts (glow type). |
| (c) Control gear | (i) | Open-circuited choke. |
| | (ii) | Open-circuited capacitor (T.L. circuit). |
| (d) Wiring | (i) | Disconnection in wiring. |
| | (ii) | Lampholders or starters not making contact. |
| | (iii) | Incorrect wiring. |

Table 13 (c)

Lamp electrodes glow continuously:—

| | |
|---|---|
| (i) | Starter switch contacts stuck together. |
| (ii) | Radio suppressor broken down. |
| (iii) | On instant-start circuit, starting switch not properly earthed. |

Many of the factors in the three above schedules are obvious and require no additional explanation.

### (9.2) Lamps

The most likely cause of lamp failure is that it has had its normal life. As has already been mentioned, the active electrode coating is necessary for starting and maintaining the discharge through the lamp. When a lamp is nearing the end of its life, this electrode coating is practically exhausted but the electrodes, still being electrically intact, complete the circuit through to the starting switch. The switch

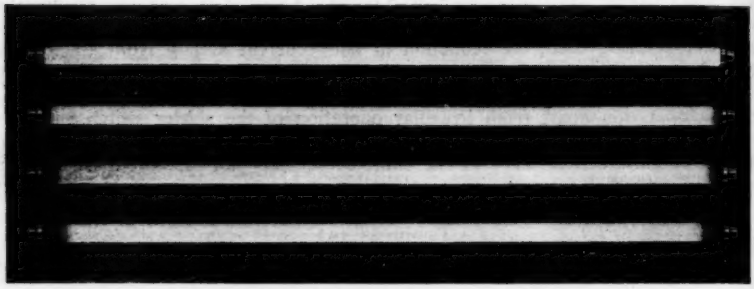


Fig. 33. End blackening of fluorescent lamps.

contacts, therefore, open and close, and the voltage surge causes a momentary "blink" in the lamp, but, because the electrode coating is exhausted, the discharge through the lamps is not maintained. This cycle is then repeated by the continued periodic operation of the starting switch, and there is a periodic "blinking," usually accompanied by a shimmering effect in the discharge. A further indication in a lamp nearing the end of its life is the deep orange-coloured glow of one or both electrodes.

At the end of life, fluorescent lamps generally show a dense blackening at one or both ends, either in the form of general blackening or as a clearly defined ring near the electrode. This end blackening is progressive throughout the life of the lamp, and Fig. 33 shows examples of a typical lamp before use, at 1,000 hours, 2,000 hours, and at the end of life. Sometimes also, dark streaks or small dark patches may appear along the length of the lamp during life. This is due to condensation of the mercury vapour on the lower, and therefore cooler, part of the lamp. Rotation through 180 deg. will give a more favourable position for evaporation.

Cracked lamps and broken electrodes should be obvious from vital examination or by testing the electrodes with any normal form of continuity tester. If only one electrode is broken a faint glow at this end of the lamp may be noted, as some of the mains voltage will exist across the broken ends.

If the lamp is faulty from other causes it will probably try to start in a similar manner to a lamp which has had a normal life and whose electrode coating is exhausted

### (9.3) Starting Switches

#### (9.3.1) *Glow Types*

The satisfactory operation of the glow starting switch depends on its voltage and time characteristics, which are controlled by the manufacturer to close limits. For example, if the "striking voltage" of the glow switch is too high, the switch contacts will not close and the lamp discharge will not start. Again, if the "extinction voltage" of the switch is too low, the switch contacts will tend to close after the

lamp has struck, causing periodic blinking. The switch will also tend to close if the voltage across the lamp is abnormally high, either due to low mains voltage or to the use of incorrect ballasting.

If the switch contacts, through some fault or incorrect spacing of the bi-metal strip, operate too quickly, the lamp electrodes may not have time to heat up before the switch contacts open again, producing repeated flashing and accelerated dissipation of the electrode coating. On the other hand, if the switch contacts operate too slowly, the lamp electrodes will be unnecessarily overloaded. Clearly, therefore, the "relative ease" of the start is important and a switch that does not start a good lamp in a few seconds should be replaced.

A normal switch will, however, outlive several lamps, and whilst the lamp life is to some extent, influenced by the total number of switchings throughout life, the lamp may be switched many thousands of times before any substantial effect on switch performance is likely to be noted. It should also be stressed that where two voltage ratings of glow switch are available 200/220 and 230/250, correct ratings of switch should be used for the particular mains voltage concerned.

(9.3.2) *Thermal Type.*

As with the glow switch, the thermal switch contacts must not break too quickly, or the electrodes will have insufficient time to become incandescent; also, the thermal current rating must correspond to that of the lamp. Thus a thermal switch suitable for a 20-watt lamp may operate too quickly with a 40-watt lamp and an 80-watt thermal switch may not operate at all on a 40-watt circuit. Use of an incorrect rating may result in the heater coil burning out.

Continuity of the heater coil may be checked across the smaller pair of contacts of the canister type switch.

(9.4) Chokes and Capacitors

Intermittent working or bad starting may be due to the wrong value of inductance or capacity in series with the lamp. As the lamp current is controlled by series equipment too low a series impedance will result in overloading of the lamp and auxiliaries and too high a value of impedance will result in inadequate current and uncertain operation. The starting and operating current should, therefore, be measured if the control gear is suspected.

An open circuited capacitor connected in series will, of course, result in non-striking of the lamp, but if connected in parallel, will only be obvious if the mains as well as the lamp-running current is measured. Capacitors should take about 72 milliamps. per micro-farad at 230 volts, and can easily be tested by connecting them across the mains with a suitable meter in series.

Short circuits in chokes and capacitors, though rare, can have more serious effects as described in section 9.5 A short circuit or partial short circuit in a choke is best checked by connecting the suspect choke in series with a similar choke across the mains and measuring the division of voltage across the chokes. A normal choke of any particular rating may be connected directly across the mains and the short circuit current should not be materially in excess of the lamp starting current.

(9.5) Wiring Faults

An earth fault in the wiring of a fluorescent fitting can cause complete destruction of one or both lamp electrodes, the starting switch, and damage to the choke coil itself. The effect of this fault will, of course, depend on the particular position of the earth in the circuit and the manner in which the phase and neutral leads are disposed. A lamp overloaded in this manner generally shows quite clear visual indications; the lamp

electrodes are blown off, the lead-in wires are fused and the electrode coating volatilised on the walls of the lamp.

Because, during the starting period, momentary voltages of the order of 800 to 1,000 may be produced, breakdown may occur in the wiring or in the radio suppression capacitor if the insulation of these components is poor. Breakdown of this capacitor may cause a short circuit across it which will effectively short circuit the lamp in which case the lamp electrodes will glow continuously and the lamp will make no attempt to start.

If the choke coil is connected in the neutral lead of the mains supply an earth fault on the wiring between the choke and the lamp or on the wiring associated with the starter switch will, clearly, short circuit the choke so that there is no limit to the current and the lamp electrode and starting switch will be damaged or destroyed. On the other hand, if the choke is connected in the phase lead an earth fault will place the choke across the mains, which will slightly overheat the choke, but as the choke is still limiting the current to the value of the choke short circuit current, the lamp electrodes or the starting switch will not be seriously damaged if the circuit is switched off in reasonable time.

It is recommended, therefore, that the choke should be connected in the phase lead of the supply. If it is suspected that a previous lamp failed through an overload, the fitting should be checked over for earth faults before a new lamp is installed.

If the lamp in the capacitive branch of the twin-lamp circuit is connected across the capacitor, catastrophic overloading will occur due to a high resonance voltage developing across the capacitor. The same effect is produced by connecting the ordinary parallel P.F. capacitor across the lamp instead of across the mains.

It is important to ensure that the heater coil of a thermal starter is wired between the choke and lamp electrode and not between choke and mains lead. In the latter case the surge voltage is applied between heater and switch contacts and is likely to cause switch breakdown.

### (9.6) Premature Blackening

Excessive blackening of the ends of the lamp, occurring early in life, indicates that the electrode coating is being dissipated too rapidly owing to abnormal operating conditions, which may result from one or more of the following causes :—

1. Overloading due to excessive mains voltage.
2. Overloading due to incorrect choke or capacitor or defects therein.
3. Defective starting switch causing lamp to blink on and off or prolonged flashing at starting.

It must be remembered that low voltage and ambient temperature conditions will cause bad starting, and bad starting, if prolonged, will result in premature blackening.

The choke rating and average mains voltage should be carefully checked and, if necessary, the starting switch replaced. A fault in a choke coil is extremely rare, but when it does occur it is sometimes not easily traced by visual inspection. A serious fault may give rise to burnt insulation or seepage of the wax through the metal container.

## (10) Conclusion

This paper has described in some detail the faults which might arise in fluorescent lamp installations, their probable causes, the symptoms by which each fault may be recognised and suggestions for rectification of those faults. It must be clearly emphasised however, that lighting failures will not occur more frequently with fluorescent lamps than the failures which occur with the more familiar filament lamps.

The important point to note is that with filament lamps, usually there is only one

cure, whereas with fluorescent lamps the cure may be any one of several. With proper procedures, maintenance may be reduced to a simple routine and full advantage taken of the efficiency and quality of flourescent lighting.

### References


(1) A. D. S. Atkinson, **Fluorescent Lighting,** p. 44 (1944).
(2) G. T. Winch and H. R. Ruff, Measurement, Representation and Specification of Colour and Colour-Rendering; Properties of Light Sources, Proc. C.I.E. (1948).
(3) R. O. Knott and J. W. P. Hudson, Starter Switches for Fluorescent Lamps, Electrical Times, **115,** 763 (1948).
(4) C. L. Amick, **Fluorescent Lighting Manual,** p. 29 (1942).
(5) F. J. C. Clack and W. A. R. Stoyle, Theory of the Twin Lamp Circuit, Electrician, p. 1983 (1949).
(6) E. S. Mills and J. H. Campbell, Fluorescent Lamps and Radio Reception, Mag. of Light, No. 5 (1940).


## Discussion

Mr. L. M. TYE, opening the discussion, said that the paper would be useful in elucidating some of the difficulties experienced with fluorescent lamps.

He had been particularly impressed with the section of the paper dealing with the smaller wattage lamps, of which there was now such a range, because, due to the pressure of time, it was not always possible to study from the ordinary catalogue the innumerable types of chokes and alternative circuits involved in their use.

In Table 2 there was an indication that the 4-ft. 40-watt tube was the most efficient in the fluorescent range. This was particularly interesting to him and to other electrical contractors who find considerable use for this size, but he had been slightly taken aback to notice in Table 3 that this lamp had a shorter life, viz. 2,500 hours as against 3,000 hours for the 80-watt and 125-watt types.

The starting current details given in Table 4 were also of interest to electrical contractors. They would all be familiar with the new I.E.E. Regulations for the loading of final sub-circuits when using discharge lamps, and of the additional margin to be allowed for their operation. In consequence it was very necessary, when applying these lamps to existing installations, to check carefully on the loading of the sub-circuits involved as, in a number of instances, it may be found necessary to rewire.

Whilst on the question of loading, he said, it would be interesting to hear from the authors regarding certain difficulties encountered when dealing with the ordinary industrial earthed type switch. He had in mind two or three installations equipped with 15 amp. size industrial switches each operating four to five 80-watt 5-ft. tubes where flash-over had taken place from the actual contacts to the earthed point of the switch and of sufficient intensity to blow the fuse. The flash-over seemed to be during the breaking rather than the making of the circuit. The same phenomenon had been experienced where a 5 amp. switch had operated a single 80-watt 5-ft. tube.

The slide which the authors showed relative to air temperatures had satisfied him that, when dealing with a cylindrical fitting surrounding the tube in fairly close proximity, the drop in actual lumen output due to temperature rise was not really sufficient to be of any moment. Of more importance, however, was the performance when two or even more chokes were contained within a lighting fitting, when the temperature rise was then a matter of some concern. The trouble was usually found to be greater in the case of elongated chokes, and he hoped the authors would be able to refer to various improvements that might be made in that particular design. He would also like to know whether it was intended to supersede the present-day elongated choke; should

this be so it would be an advantage to have additional tappings on chokes of the 200/210 volt range due to the speed in which these lower voltage supplies are being supplanted.

He had from time to time noticed a tendency on the part of various makers to drop the usual twin-tube circuit on fittings of the two tube 40-watt size, and he would like to know why this was so.

Starter switches were an item of considerable interest to contractors, particularly at this time of the year when voltages tended to be low. He generally preferred the glow type of starter switch because it did not seem quite so susceptible to current drop as the thermal type. Moreover, he had experienced certain difficulties in matching up thermal switches to various types of chokes of the same wattage rating.

He also asked if the authors could give any figures on the life of tubes used on D.C. supplies now that so many were being used that way.

He congratulated the authors on the ingenious testing equipment demonstrated and thought it would be a good thing if everybody concerned with the maintenance of fluorescent lamps had such an equipment available.

During the last few weeks he had noticed a tendency with various makes of tubes for premature blackening at the ends of 5-ft. 80-watt tubes. It was difficult to understand why tubes were supplied in this condition, and still more difficult to convince the customer that the tubes were sound. If it had happened with one particular batch he could understand it, but it has happened with one or two consignments of different makes.

Finally, he said, he felt that fluorescent lighting was not in every instance being used to the maximum advantage and we were to a certain extent being faced with the conditions which prevailed in the early days of the tungsten lamp when it was common to find the advantages were nullified by incorrect use and placing. The lamps were not always being used in the correct manner and he felt that considerably more technical and planning data relative to the correct application of fluorescent fittings was required to enable an engineer to work out easily and accurately intensity figures which he could expect to obtain, thus making the interpretation of the I.E.S. Code much simpler to attain.

Mr. G. S. ROBINSON said there were two questions he would like to ask. The first was in connection with Table 10, which gave a list of the various starter switches for use with different lamps. In that table it would seem that the thermal switch could be used with every type of lamp and every type of circuit, whereas the glow switch had definite limitations. The respective circuits had been dealt with by the authors and it seemed there was no particular advantage in either one type or the other. Therefore there would be considerably less confusion if there were one type of switch for all circuits; which apparently would be the thermal switch.

His second point was in connection with chokes. There were now chokes available in 10-volt steps from 200 to 250 volts. That was understandable, as the industry is quite accustomed to using apparatus rated for different voltages. The difficulty arose when one came to the twin lamp circuit and also the series circuits for the low wattage lamps. Then it would be found that chokes were apparently being used on the wrong voltage. For instance, in one twin lamp circuit, a 200-volt choke was used on one side and a 250-volt choke on the other. To the ordinary man carrying out an installation that was rather confusing and complicated, and there was a definite risk of putting the wrong choke in the wrong place. Was there any possibility of simplifying that?

Mr. G. P. LYNAS also referred to the question of chokes in the twin lamp circuit where a 200-volt choke is used for one lamp and 250-volt choke for the other lamp. His experience had been that the average electrician did not appreciate the actual need for this, and it had been found in some cases that a faulty 200-volt choke had been

replaced with a 250-volt choke on twin lamp circuits. Some clearer indication should be given of the position of the two types of choke in the fitting. Starter switches, he said, were, in the main, reliable, but he had found many cases where an old lamp had been replaced, without replacement of the starter switch, and then the starter switch had failed about half way through the life of the new lamp, with the consequent reduction in the life of the new lamp.

He also thought that there was a good case for the instant-start circuit even if it be a little less efficient.

Mr. E. P. GIBSON remarking that the paper had given both pleasure and valued instruction to all, said that the information given in the paper was urgently required by electrical maintenance staffs who were now engaged in change-over work with this new method of illumination. He, therefore, suggested that the information should be published in book form.

His experience with fluorescent lighting had been a demand for further installations and, at the same time, queries from the installation staff on such points as:—Why are instant-start circuits not more frequently employed in view of the fact that they reduce a potential source of trouble; to what extent is beryllium powder now used; why do we have to continue with bi-pin holders which are not always satisfactory; how do the Americans attain higher efficiencies with their lamps; why do some lamps blacken more quickly at the ends than others?

He said he would be glad if the authors could answer these questions.

Mr. A. R. MCGIBBON said his first point was with regard to the correct type of switch to use for fluorescent lighting circuits and asked whether the quick make and break, the slow make and break or the micro-switch was the most suitable.

He then dealt with the question of the possible fault current developing inside a fitting. If a fault occurred with a filament lamp fitting it usually blew the fuse and the fault could be traced before replacing it, but with fluorescent lighting fittings the choke could limit the current so that the fuse would not blow and, if the circuit switch were on the wrong side, the fault might pass unnoticed for some time. Had this been considered in the design of chokes? It would be interesting to know what was the maximum fault current in the case of the ordinary 80-watt choke.

Referring to the testing set that the authors had mentioned, he asked if this were to be marketed commercially or if it were merely a laboratory set-up.

In connection with storekeeping, he urged the necessity for clearer marking of the lamps and components in view of the fact that many storekeepers were elderly and had to make considerable use of their spectacles to read the rather faint markings.

As regards the simplification of the range of fittings already mentioned, he said that, when looking through manufacturers' catalogues, it was horrifying to see the amount of auxiliary apparatus that was available in connection with fluorescent lamps and he felt it would be better to reduce the range even at the cost of some reduction in efficiency. It would be an advantage to the installation engineer and, he would imagine, also to the contractor who had to stock these things.

Mr. R. V. MILLS, commenting on the reference in the paper to the difficulty of starting fluorescent lamps at low temperatures when the supply voltage was below 200 volts, asked if this was because the lamp required a longer pre-heating period. Could not this trouble be cured by having a thermal starter with a longer closed period to give better starting in cold temperatures?

With regard to tumbler switch flash-over, he had investigated cases of alleged

tumbler switch failure and had found that, if a power factor correction capacitor was included on the lamp side of the switch, it materially reduced the severity of arc rupture when the switch opened; in fact, with the power factor correction capacitor connected, the surge appearing across the switch is less than that obtained with an equal tungsten lamp load.

No reference had been made in the paper to rectification during starting which occurred if a lamp cathode was fractured. It was possible in such cases for the rectified current to be in excess of the normal starting current, and this resulted in the destruction of the starter. It was, therefore, important to check the continuity of the lamp cathodes in a circuit which was found to have a fused or welded starter.

Mr. M. GAUGHAN, commenting on the reference in the paper to the advantage of the capacitative circuit when the voltage was falling, said he hoped this would not encourage contractors to go away and install capacitative circuits wholesale. He came across one such case in which there was no appreciation of the fact that this circuit would give a leading power factor of 0.5, and it was essential to watch the cables under those conditions.

An advantage of using the capacitative circuit was that it tended to prevent partial half-waving. The flicker on certain lamps was very much worse than on others and this was very often due to partial rectification or half-waving, and the capacitative circuit tended to reduce that. He believed that London Transport now used this circuit exclusively since their 33⅓ cycles supply made half-waving particularly objectionable.

Mr. STANLEY L. LYONS said that, whilst he had been extremely interested in the paper, he was a little disappointed because he had hoped to hear more about direct-current circuits. He had recently experimented with new units for operating fluorescent lamps on direct current; these incorporated three mercury switches worked by electro-magnet and delay mechanism which arrangement automatically reversed the polarity with each switching period, and dispensed with the usual type of starter-switch. Was there any possibility of this becoming a standard circuit, and did the authors think that it was a good thing?

Mr. J. MORTIMER HAWKINS, referring to lamp life, said the definition of this seemed to be dealt with very vaguely by the manufacturers in terms of hours, whereas the Electrical Research Association had defined it rather more helpfully, in his view, as the highest number of hours, he believed the figure was 5,000, less so many hours per switching operation. That seemed to him to be less misleading. It appeared that quite a substantial reduction in life was represented by switching.

He asked why manufacturers had stopped making the tapped choke as, from the point of view of stocking and control, it simplified things very considerably.

With regard to earth leakage protection, this had been successfully demonstrated on cold cathode lighting using a differential relay, and he had been in touch with manufacturers in this country and America trying to find out why it was not employed or investigated further. It seemed it could be produced cheaply and would eliminate fire risk which, in some circumstances, could be dangerous.

THE PRESIDENT, commenting on what had been said on the identification of components in store, suggested that a simple colour code might be the answer to that problem from the point of view of the storekeeper.

Mr. C. R. BICKNELL thought it would be useful if the authors could indicate what period of time they considered might be allowed to elapse between the changes of polarity when the lamps are operated on D.C. The recommendations in the paper are

that the polarity be changed each time the lamp is switched on and, if the lamp starts to blacken at other times, to reverse the polarity. He appreciated the difficulty of making recommendations in this respect, but even a fairly broad indication of suggested practice would be helpful.

A point in which he had been greatly interested with regard to these lamps was radio interference. In referring to it, the authors had stated that the broadcast band of 200 to 500 metres was most affected. Some investigation with which he had been concerned some years ago showed that, in the case of very short wave reception, the interference is extraordinarily selective, and he quoted from test results to exemplify this.

The authors recommended that, where it is necessary to fit a mains filter, it is preferable that it be fitted in the lamp supply leads rather than in the leads to the receiver. He felt that the simplification of fitting it into the receiver supply leads made this method preferable if adequate suppression of interference could thus be obtained.

Mr. E. WOOD said that, in connection with the testing of capacitors, the authors gave a figure of 72 milliamperes per microfarad whereas in an article in LIGHT AND LIGHTING some months ago a figure of 45 milliamperes per microfarad was given. The first figure was correct at 230 volts 50 cycles. As there would be different mains voltages, would it not be advisable to give the various currents for each voltage or at least state that the figure of 72 related to 230 volt, 50 cycles?

The testing set described by the authors provides a very useful means of testing fluorescent lamp circuits. It would, however, have to be used by personnel having an intimate knowledge of the circuit. When mains voltage is being tested, the choke and voltmeter are in series. Could the authors state the value of the impedance of the choke and voltmeter being used and was the voltage drop across the choke negligible compared with that across the voltmeter? There would also be the possibility of a wrong conclusion being arrived at, viz., that there was no mains voltage in the event of an open circuit in the choke winding.

Mr. R. PELERIN said he had had some experience of using testing sets and had found it was necessary to be very careful in interpreting the results. This required someone very familiar with the apparatus under examination and, if the sets were to be used in the lighting industry generally, they might prove dangerous weapons.

It had been suggested during the discussion that the paper should be turned into the form of a book. He agreed whole-heartedly with that view but his experience in this connection had shown that the greatest difficulty in disseminating such knowledge was to get the user of the fluorescent lamp to read it. There was much knowledge in the standard literature issued by manufacturers and many of the questions asked during the discussions were answered in that literature. Therefore, having got this information in the form of a book, there still remained the difficulty of getting the user to read it and fully understand it.

Mr. STOYLE, making the first reply to the discussion, said that the efficiency of the 40-watt lamp relative to the 80-watt lamp was a matter of current density, the current density of the 40-watt lamp enabling it to make use of the ultra violet radiation rather more efficiently. It was a fact at present that the life of the 40-watt lamp was less than that of the 80-watt and 125-watt lamps, but it was anticipated that, with improvements in manufacturing technique, there would be more consistency between the different lamps.

As to flash-over on switches, that point had been raised before and, quite frankly, he confessed there was something confusing about it. When he first heard of this trouble he had tests made, but there was no flash-over after 45,000 switchings on a bank

of four 80-watt lamps. The conclusion he came to was that in certain types of switch the contact was rather close to the earthed part of the switch.

The elongated choke, he said, had been designed not from the point of view of efficiency, but from the point of view of convenience in size and for fitting into a very narrow channel. The result was a choke which was not so efficient as the cubic choke. Both types could, however, be obtained.

There was not much information available with regard to the life of fluorescent lamps on D.C., because this type of lamp was not in use in sufficient quantities to enable a statistical average to be obtained. From his personal experience, however, he should not think there was any material difference in the life of lamps on A.C. or D.C.

The question of the blackening of relatively new lamps was, to some extent, a manufacturing fault, and with the new manufacturing techniques now coming into use it was anticipated that this difficulty would be largely eliminated.

In reply to Mr. Robinson, he said he could not agree more on the advantage of having one type of thermal switch, but he did not see any immediate prospect of one or otner type being universally acceptable in the immediate future owing to the requirements of the lower voltage shorter lamps which differed from those of the longer lamps.

With regard to the different ratings of the chokes in twin lamp circuits, which had been mentioned by various speakers, he said that, whilst this was deplored, he did not see any immediate solution. It was a thing which must be accepted for the moment.

Referring to the comment by Mr. Lynas, he said he should not have thought it necessary to replace the starter each time a lamp was changed. The life of the starter was usually at least that of the life of three lamps although there might be odd occasions when the starter had to be replaced when the lamp was replaced.

Mention had been made by Mr. McGibbon of the possible fault current. That was an old controversial subject and one upon which he thought it would be helpful if there were a ruling by the Wiring Rules Committee. Personally, he had had no experience of danger that had resulted from a fault current.

He said he had seen test sets advertised in the electrical Press and the one he had described would be marketed in the near future.

In connection with starting lamps under cold conditions and the advantage of a sluggish starter, mentioned by Mr. Mills, he said that this would help. If the mains voltage was not sufficient, however, the lamp would not start easily.

There were quite a lot of theories on the effect of D.C. rectification, but he had never been able to measure any very large amount of rectification. Even with the lamp electrode broken at one end, he had never been able to make the D.C. current higher than 20 or 30 ma., or sufficient to have any significant effect on the auxiliary gear.

The point mentioned by Mr. Gaughan on the advantage of the twin circuit in reference to half-waving was one which had been omitted from the paper, but he agreed with what had been said.

As regards putting some kind of coating on the tube to prevent moisture settling on the lamp, mentioned by Mr. Harrison-Jones, this was quite a well-known procedure and might be quite effective, but he still thought the other arrangement was neater and technically more satisfactory.

Reference had been made by Mr. Lyons to the use of an automatic reversing switch on D.C. circuits. This was a well-known idea, but he had not dealt with it in the paper because he felt it was of relatively minor importance. The intervals at which a lamp should be reversed in these circumstances depended on the length of the lamp: short lamps would run for a long time before any electrophoresis or cataphoresis was evident.

He did not think there was any desire on the part of fluorescent lamp manufacturers to hide the fact that the number of times of switching had a relation to the life of the

lamp, and the average of 3,000 hours was based on three hours per start. It was quite true that, if the fluorescent lamp was switched on and off at long intervals, the life would be two or three times what it was now, on the average, but the number of switchings would have to be increased very considerably before any great decrease in life resulted.

He agreed that the tapped choke, which manufacturers had stopped making, was a very useful one but it was more expensive and larger.

He agreed with Mr. Mortimer Hawkins about the large amount of auxiliary gear that was on the market, but he felt it was inevitable in a period of gestation such as the present one in this revolutionary field of lighting and it was to be hoped that things would settle down in the not too distant future.

On the question of radio interference, he agreed with Mr. Bicknell that the suppressor was better placed in the actual receiver leads of the wireless set. Radio interference was a matter which was receiving close attention at the present time particularly because of the new legislation. A good deal of work had to be done in this connection but he had no doubt that it would result in increasing our knowledge of the subject.

Replying to Mr. Wood with regard to the 72 ma., mentioned in this paper and the 45 ma., mentioned in another article, he said it rather seemed that his mistakes had caught him up. He could not tell Mr. Wood the impedance of the choke off-hand, but, before the lamp had struck the voltage drop across the choke imposed by the voltmeter, load was negligible.

Mr. G. D. JONES-THOMAS replied to other points raised in the discussion.

Commenting on some of the matters raised by Mr. Gibson, he said he did not know why the instant-start circuit was not more frequently used, although he himself thought it was an admirable circuit. The only objections raised against it were that the lamp had to be earthed and it required another piece of fairly expensive gear. It also lowered the over-all efficiency to some extent.

With regard to the use of beryllium powder for lamps in this country, he said that most British lamp makers had not used this for about two years. Reports of alleged beryllium poisoning seemed to emanate from other countries and should be treated with reserve.

He agreed that bi-pin holders were not entirely satisfactory but considerable work was being done to see what modifications could be made as there was certainly room for improvement.

As to the higher efficiencies which were said to be obtained in America, he said this was a question of better facilities for manufacture and the use of different colours. The Americans used more yellow and green than we did, and higher efficiencies were obtained in that way.

Finally, with regard to the testing set, he said that any fool-proof device was dangerous in some hands. The testing set that had been shown that evening would be coming on to the market and a booklet would be sent out with it, written in such a way that it was expected that everybody would be able to understand it and operate the set satisfactorily.

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*With a view to avoiding possible confusion with other publications, reference to these Transactions should be in the form:—"Trans. Illum. Eng. Soc. (London)."*

## Additions to List of Members

The following applicants have been duly elected by the Council to membership in the Society, and their names have been added to the list of members.

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Newbery, D. F. J. ..... 15, Brandwood Road, Kings Heath, BIRMINGHAM, 14.

## Fellowship

The Council have accepted the following application for Fellowship of the Society:—
J. S. Smyth.

## Register of Lighting Engineers

The Council have accepted the following applications for inclusion on the Register of Lighting Engineers:—
N. Blackman, G. C. Jones, T. D. Smith, V. G. Wackrow.

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